Saratov Fall Meeting'20

Mathematical modeling of impact endothelial mechanism in the regulating vascular tone

Elena S. Litvinenko and D. E. Postnov

Saratov State University

Microcirculation is the transport of biological fluids at the level of body tissues: the movement of blood through microvessels of the capillary type (capillary circulation), the movement of interstitial fluid and substances through the intercellular spaces and the transport of lymph through the lymphatic microvessels.

Vascular tone is a condition of the vascular wall that creates resistance to blood pressure. Determined by passive components - collagen and elastin, and active - smooth muscle cells and endothelial cells.

Endothelium-mediated mechanism -- reactions of endothelial cells to changes in the linear velocity of blood flow in a vessel.

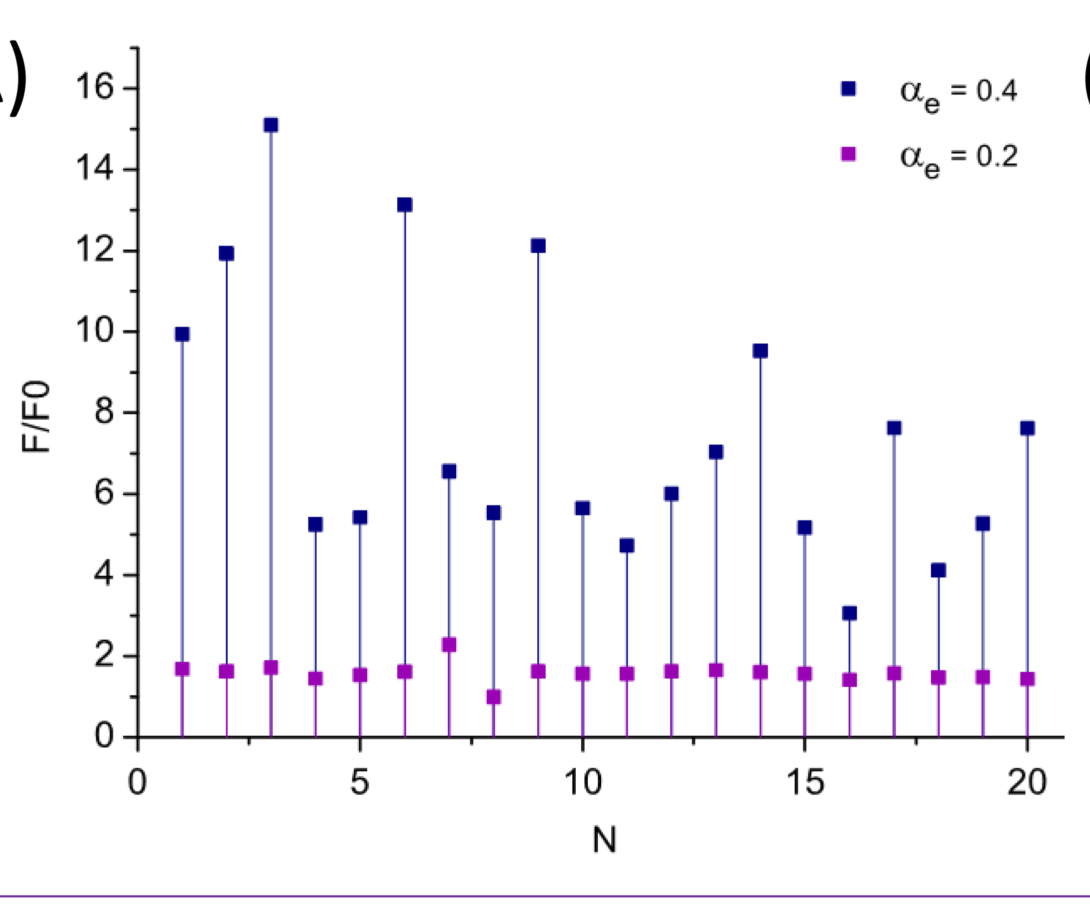
The mathematical model we have created allows us to study the contribution of endothelium-mediated mechanisms of autoregulation of vascular tone to the dynamics of microcirculatory networks. The developed mathematical model of a vessel segment conventionally includes two subsections: flow modeling by the type of windkessel models, and modeling of dynamic regulation of the degree of elasticity of the vascular wall, mediated by the work of endothelial cells and smooth muscle cells. A detailed description of the model can be found in our previous works:

Stiukhina E. S., Avtomonov Yu. N., Pos tnov D. E. Mathematical Model of Vascular Tone Autoregulation. Izv. Saratov Univ. (N. S.), Ser. Physics, 2018, vol. 18, iss. 3, pp. 202–214 (in Russian). DOI: 10.18500/1817-3020-2018-18-3-202-214

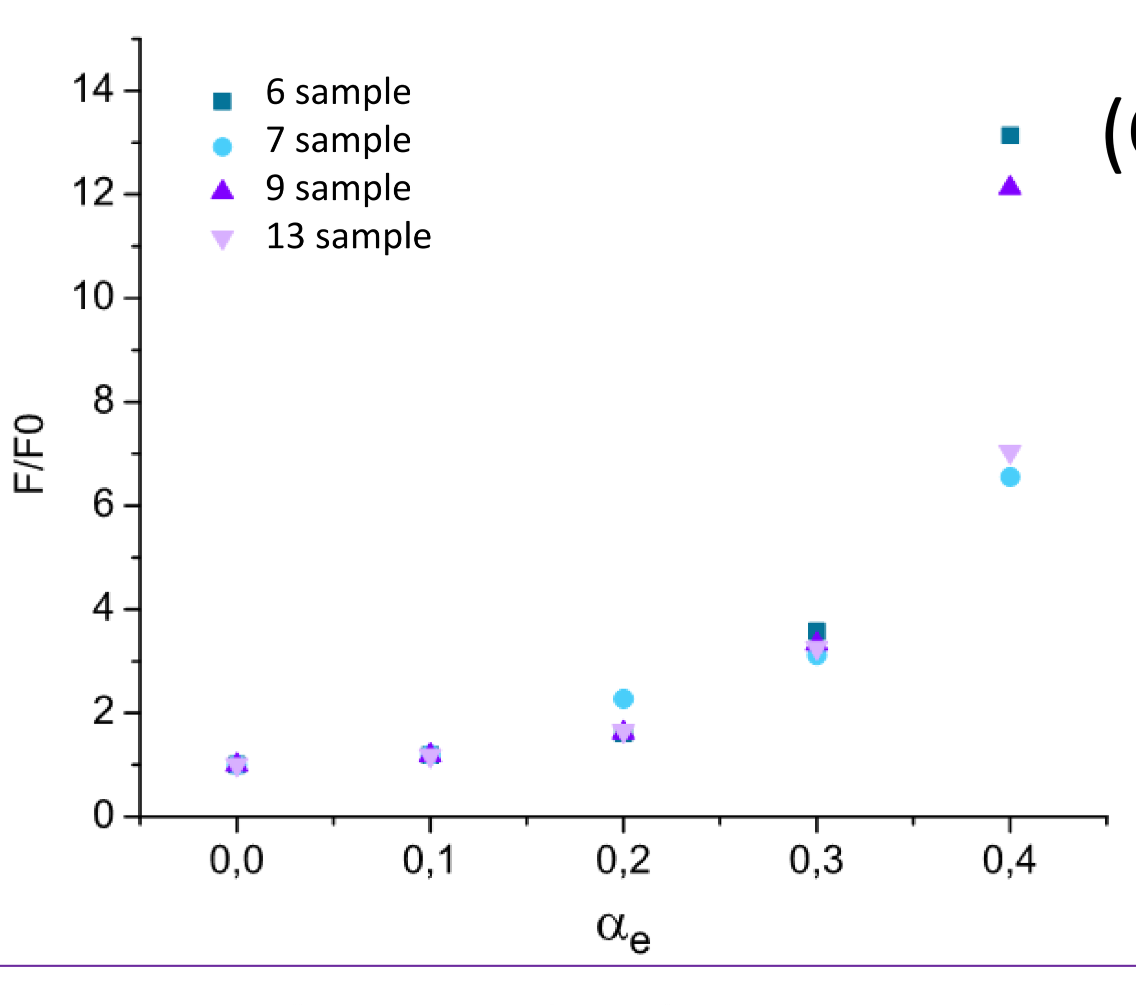
Avtomonov Y. N., Stiukhina E. S., Postnov D. E. Computational study of endothelial-mediated vascular responses at Y-bifurcation: when occlusion does not reduce the total flow //Saratov Fall Meeting 2018: Computations and Data Analysis: from Nanoscale Tools to Brain Functions. – International Society for Optics and Photonics, 2019. – T. 11067. – C. 1106714.

New computational results

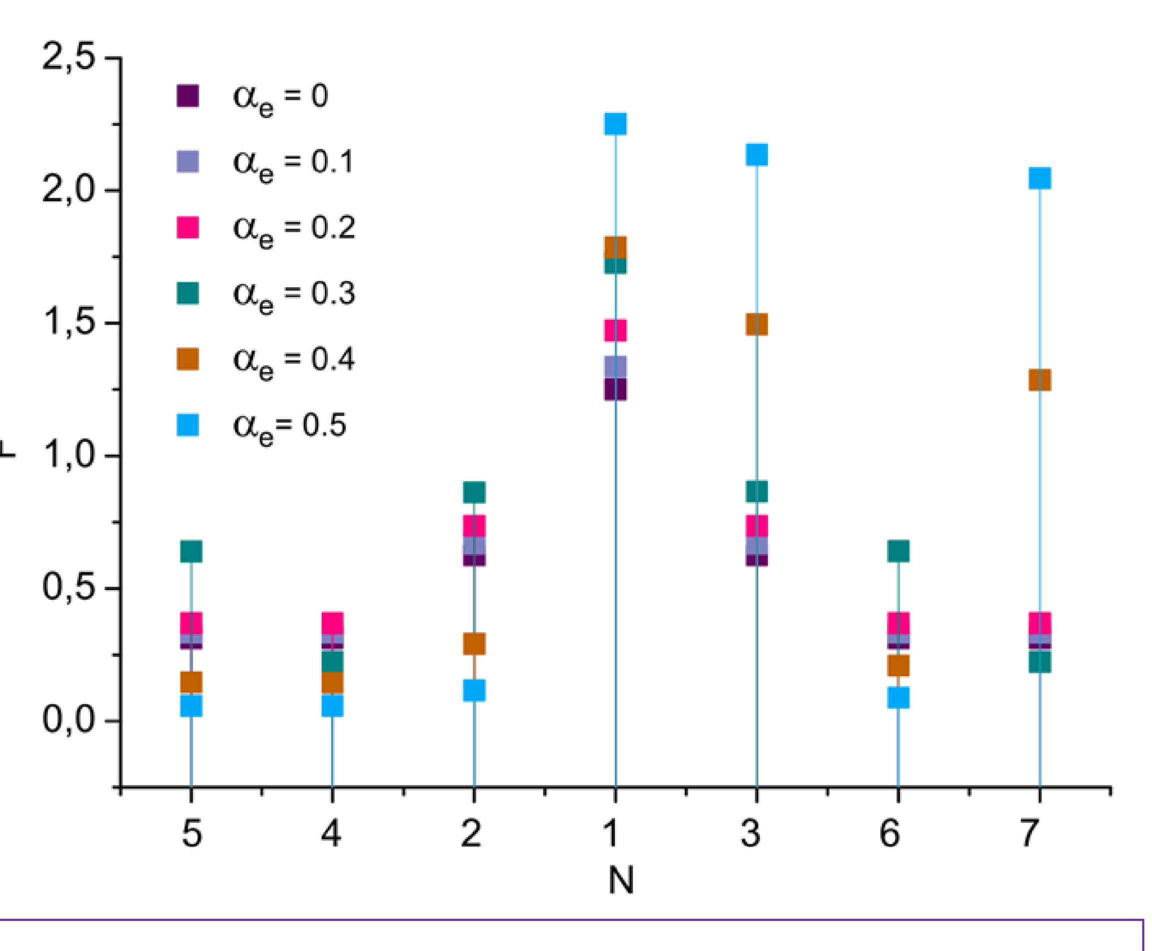
(A)



(B)



(C)



The circulatory network was modeled as a binary tree of 7 arterial and 7 venous segments. The computational results of the venous network will not be presented in the future, since the venous system is weakly amenable to endothelial regulation. The task was not just to study the behavior of a single sample of a network with a given set of parameters, but to identify typical reactions that are characteristic of a given network topology. For this, a computational experiment was carried out on a set of 20 different model network implementations with the same topology

(A) The change in the input flow was investigated for a set of 20 networks at different values of the degree of endothelial activation. And it was shown that at low values of the degree of endothelial activation (αe), the flow increases insignificantly and there is practically no spread in it.
However, with stronger endothelial regulation, the spread of fluxes increases many times, from which it follows that endothelial regulation makes a significant and varied contribution to changing the state of each of the networks

(B) The graph shows the relative change in the incoming flow for four selected network implementations depending on the value of αe. Up to αe = 0.3, the incoming flow increases relatively evenly in all selected networks. With a further increase αe there is a sharp increase in the flow, as well as an increase in the spread in values for specific network implementations

(C) We chose a simple 7-segment network in which the diameters and lengths of all vessels are the same. During the computational experiment, the intensity of endothelial activity changed. The results of the experiment showed that up to the value of αe = 0.2, the network has synchronization in the distribution of flows. With an increase in endothelial activity, desynchronization appeared in the third-order vessels. Then, in the vessels of the second order, and simultaneously with this, the flows of the vessels of the third order are synchronized.

The endothelial regulation mechanism manifests itself in a complex way, depending on the strength of endothelial regulation on the vascular bifurcations, an imbalance of strong flows is observed and vice versa, the restoration of symmetry in the branches with a reduced blood supply